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Atomic Structure of $L1_0$-FePd Nanoparticles studied by High-resolution Transmission Electron Microscopy

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Hard magnetic properties of FePd alloy nanoparticles originate from their $L1_0$-type tetragonal ordered structure with a high magnetocrystalline anisotropy energy. A correlation has been reported between the long-range order parameter and the particle size based on nanobeam electron diffraction [1]. However, the detailed nanostructure of small FePd nanoparticles is not fully understood. In this study, spherical aberration (C_s) corrected transmission electron microscopy (TEM) was employed for high-resolution observation of the atomic structure of FePd nanoparticles 2-10 nm in diameter. Besides its highly improved spatial resolution, a C_s-corrected TEM has a small optimal defocus condition due to a small C_s value ($\Delta f = (4/3C_s\lambda)^{0.5}$), which results in clear visualization of particle surface region.

FePd nanoparticles were fabricated by successive deposition of Pd and Fe onto NaCl(001) substrates at 673 K [2]. After the deposition of Fe, an amorphous Al_2O_3 thin film was deposited to protect the particles from oxidation. Post-deposition annealing at 873 K led to a formation of the $L1_0$-type ordered structure. High-resolution TEM (HREM) images were obtained by using FEI Titan 80-300 TEM operated at 300 kV with a field emission gun and a C_s corrector for the objective lens. All TEM images were recorded by using CCD camera attached to the TEM.

HREM images of FePd nanoparticles with c-axis oriented normal and parallel to the film plane are shown in Figures 1(a) and 1(b), respectively. Periodic arrangement of atoms due to chemical order is clearly seen as bright contrasts due to a small negative value of corrected C_s. Fourier transforms also indicated high spatial resolution. Particle periphery, i.e., the interface between crystal and amorphous, is also clearly observed. The analyses of power spectra of the amorphous region led us to conclude that the defocus value is about 13 nm, which is much smaller than the typical Scherzer defocus value (40-50 nm) for conventional high-resolution microscopes. A clear-cut long-range order is lost when particle size is smaller than about 5 nm, and partially ordered particles become dominant. It may be suggested that smaller optimal defocus is suitable for precise observation of atomic structure of nanoparticles.

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References

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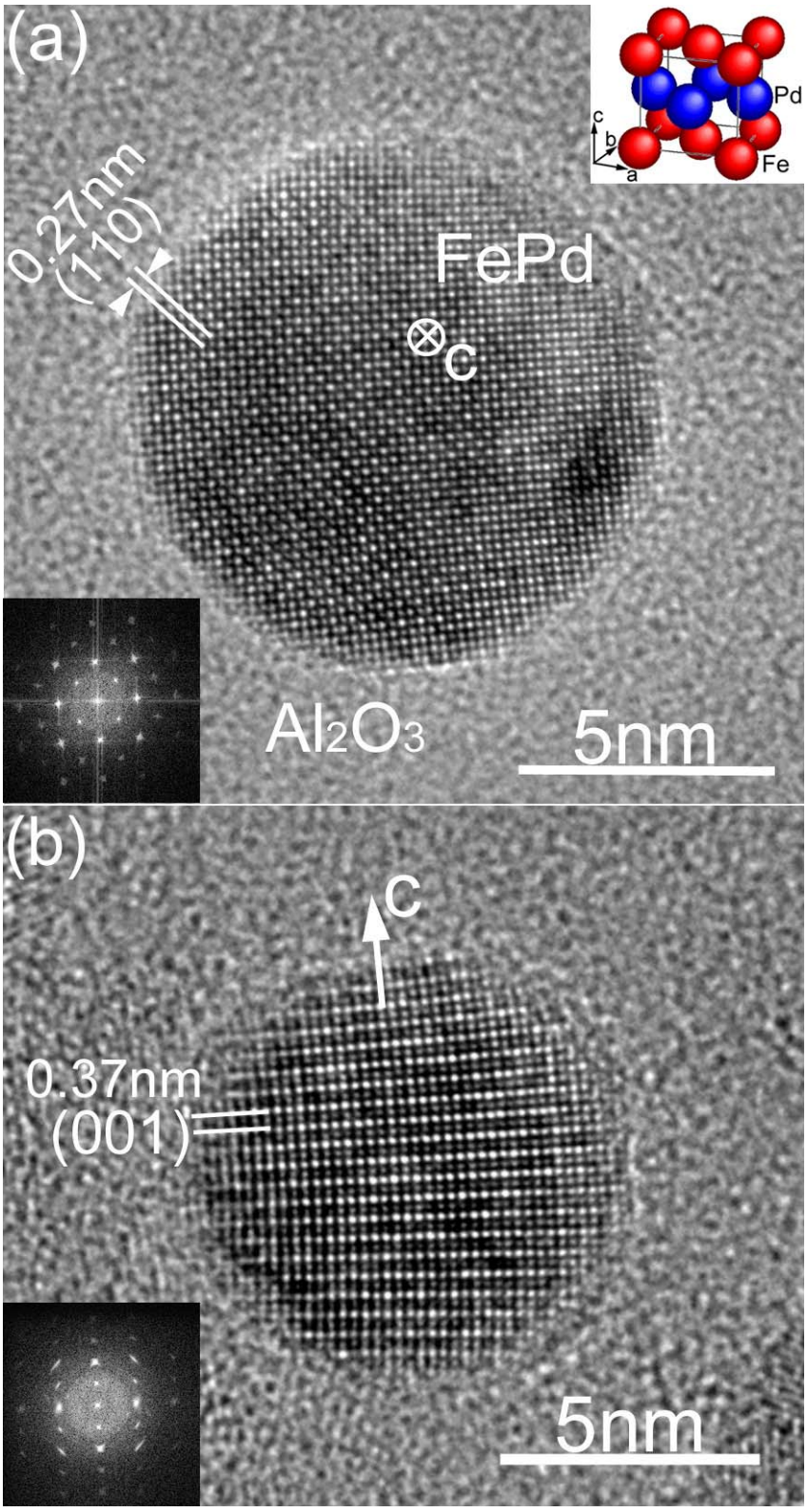

FIG 1. HREM images of FePd nanoparticles with the $L1_0$ structure: (a) beam || [001], (b) beam || [100]. A schematic illustration of the $L1_0$ structure is shown in the inset.